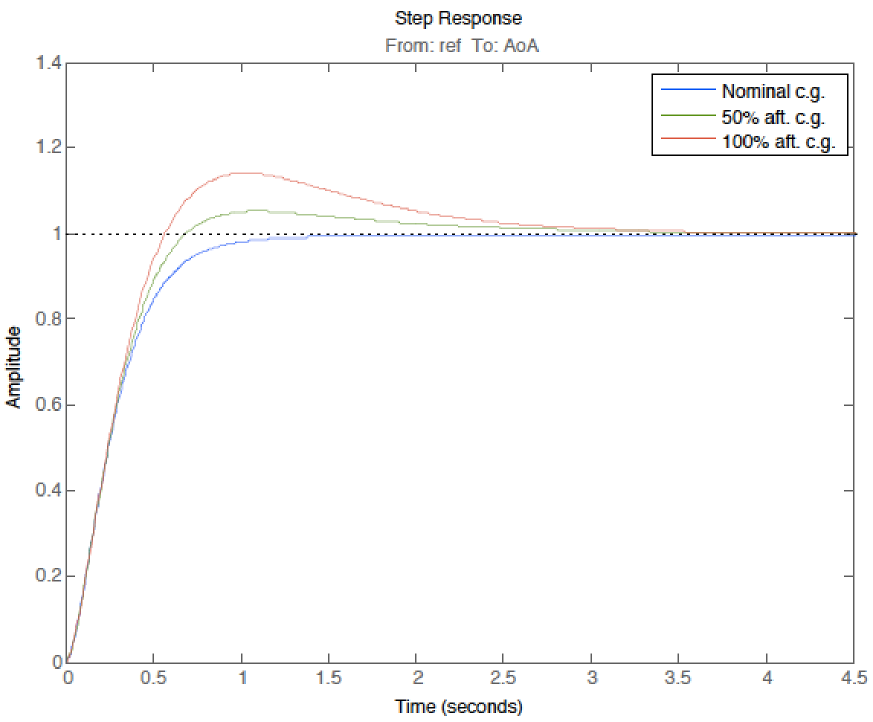
ROBUST MRAC AUGMENTATION OF FLIGHT CONTROL LAWS FOR CENTER OF GRAVITY ADAPTATION

Daniel Simon, daniel.simon@saabgroup.com

BACKGROUND AND MOTIVATION

- The center of gravity (c.g.) changes over time
  - Slowly due to burning of fuel
  - Abruptly due to release of weapons
- Difficult to safely estimate c.g. position
- A performance vs. robustness trade off



ADAPTIVE AUGMENTATION OF NOMINAL FCS

- Designed for the short period dynamics

$$\dot{x}(t) = Ax(t) + Bu(t)$$
$$x(t) = [\alpha \;\; q]^T \;\; r(t) = \alpha_{cmd}(t)$$

- Nominal pitch dynamics controller

$$u_{nom}(t) = -Lx(t) + Fr(t) + \int (\alpha_{ref} - \alpha)\mathrm{dt}$$

- The matrices A and B vary with the change in c.g.

- We want to add an adaptive control to the nominal controller

$$u(t) = u_{nom}(t) + u_{ad}(t)$$

MODEL REFERENCE ADAPTIVE CONTROL

- The aircraft is modelled as an uncertain system

$$\dot{x}(t) = Ax(t) + B\Lambda u(t)$$

- Model Reference Adaptive Control (MRAC) estimate controller parameters online

$$u(t) = -\hat{K}_x x(t) + \hat{K}_r r(t)$$

- Estimation based on reference model

$$\dot{x}_m(t) = A_m x_m(t) + B_m u(t)$$

- Requires “model matching”

$$A - B\Lambda\hat{K}_x = A_m, \quad B\Lambda\hat{K}_r = B_m$$

MODEL REFERENCE ADAPTIVE CONTROL

- The adaptive controller parameters are updated online in real time.
- The update scheme can be based on so called Lyapunov Theory.
- The updates equations are

$$\dot{\hat{K}}_x = \gamma_x \text{sgn}(\lambda)(x - x_m)^T PBx^T$$

$$\dot{\hat{K}}_r = -\gamma_r \text{sgn}(\lambda)(x - x_m)^T PBr$$

- These update laws can be robustified to handle noise etc.

$$\dot{\hat{K}}_z = \begin{cases} \text{Proj}\left(\hat{K}_z, \gamma_z \text{sgn}(\lambda) e^T P \tilde{B}^0 z^T\right) & ||e(t)|| > \epsilon \\ 0 & ||e(t)|| \leq \epsilon \end{cases}$$

$$\dot{\hat{K}}_r = \begin{cases} \text{Proj}\left(\hat{K}_r, -\gamma_r \text{sgn}(\lambda) e^T P \tilde{B}^0 r\right) & ||e(t)|| > \epsilon \\ 0 & ||e(t)|| \leq \epsilon \end{cases}$$

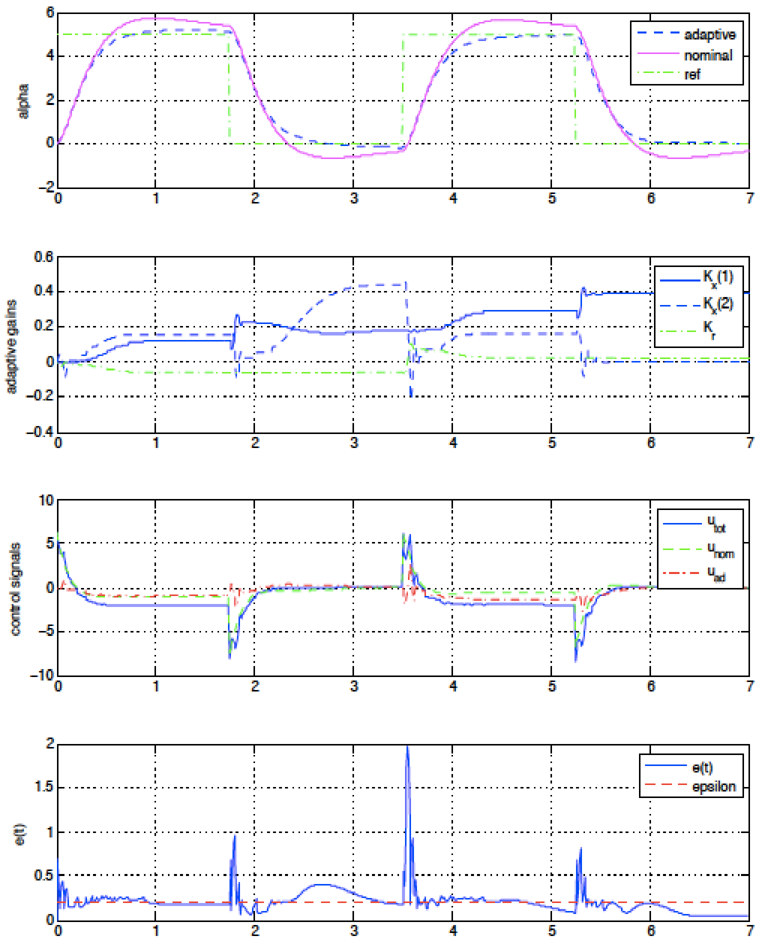
SATISFYING THE MODEL MATCHING CONDITIONS

- The short period dynamics model does not fulfill model matching conditions
- Instead model the uncertain system using $z(t) = [\alpha(t) \;\; \dot{\alpha}(t)]^T$
- The total control law become

$$u(t) = -Lx(t) - \hat{K}_z z(t) + (F + \hat{K}_r) r(t) + \int (\alpha_{ref}(t) - \alpha(t)) \mathrm{dt}$$

SIMULATION RESULTS

- Simulated system with c.g. in most aft position
- Compared nominal controller with nominal plus adaptive augmentation
- The adaptive controller “learns” the optimal parameter settings
- Note the optimal adaptive augmentation is almost only angle of attack feedback!



CONCLUSIONS

- MRAC can be difficult to tune
- Closed loop unstable for certain tuning parameters
- Not scale invariant for input signals
- Normalized adaptive laws needed
- Interesting to only use an adaptive angle of attack feedback

- MRAC is an interesting methodology for future research.

This work has been funded by NFFP/Vinnova/FMV/Swedish Armed Forces

CREATING **EFFECTIVE** PRESENTATIONS

- A few rules of thumb
  - Try to stay to maximum 5 bullets and 2 lines for each bullet
  - Keywords only, no sentences, no full stops
  - English (UK) is Saab corporate language
- We only use these fonts and sizes…
  - Titles in uppercase Arial and Arial Black (32pt)
  - Texts and bullets in lowercase Arial (20pt)
  - Secondary bullets and supporting text in Arial (16pt or 12pt)
- …and these colours
  - Grey (RGB 75, 75, 75), texts and boxes
  - Light grey (RGB 205, 205, 205), boxes
  - White (RGB 255.255.255), texts in boxes
  - Dark blue (RGB 0, 36, 89), boxes
  - Light blue (RGB 73,151,192), link texts

PowerPoint resources and best practice available here

Download Saab images here

How to change document settings:

- Click the View tab
- Choose Slide Master
- Select the top slide in the left column
- Edit your information in the upper right corner of the slide
- Close Master View
- More on how to classify company information is found here